

Investigation of the Thin-Layer Drying Characteristics of Cow Bone as Source of Nutrients for Plants

I.C. Ekeke¹, M.M.Chukwu^{2*}, C. Ononogbo³, J.C. Obijiaku^{1,4}

¹Department of Chemical Engineering, Federal University of Technology,
P.M.B 1526, Owerri, Nigeria.

²Department of Chemical Engineering, University of Agriculture and Environmental Sciences,
Umuagwo, P.M.B. 1038 Owerri, Imo State, Nigeria.

³Department of Mechanical Engineering, University of Agriculture and Environmental Sciences,
Umuagwo, P.M.B. 1038 Owerri, Imo State, Nigeria.

⁴Ralph E. Martin Department of Chemical Engineering, University of Arkansas,
Fayetteville, AR 72701, USA.

ABSTRACT: The study of the thin-layer drying behavior of cow bone was carried out in a laboratory scale oven. The study considered the impact of the drying time, sample thickness, drying temperature, and interaction between time and temperature on the moisture ratio of the cow bone samples. Ten thin-layer drying models used in the study were fitted to the moisture ratio data. Among the drying models investigated, the Page model satisfactorily and best described the drying behavior of the cow bone. In addition, regression analyses of the results revealed that time and the interaction between time and temperature played significant roles in the moisture ratio of the bone samples, which agrees with the content of literature. Furthermore, on application of the optimization tool of the MATLAB program used, the minimum of constrained nonlinear multivariable functions gave the optimum values of drying temperature, drying time and slice thickness to be 120°C, 356mins and 10mm, respectively for the bone samples investigated. This optimization result is particularly important in the identification of the optimum drying conditions for the product sample in order to avoid unnecessary energy waste. This is because drying the sample at a higher temperature will surely consume more energy with little or no effect on its drying rate, thus increasing the level of environmental pollution; as higher energy consumption is tied to more fuel combustion. The outcome of this study is very essential to farmers in the processing of bone meal for plant nutrition.

KEYWORDS: cow bone, drying, thin-layer, drying models, temperature, optimization

<https://doi.org/10.29294/IJASE.9.1.2022.2488-2496>

©2022 Mahendrapublications.com, All rights reserved

INTRODUCTION

Animal bones are used in producing bone meal which serves as a good source of calcium and phosphorus in plants. Most vegetable plants benefit from an annual application of bone meal, but it is particularly beneficial for root crops, including carrots, onions, radishes, parsnips and turnips [1]. Flowers grown from bulbs, corms and tubers also benefit from an application of bone meal. The calcium infusion from bone meal helps plants develop strong and healthy cells and seeds. It also strengthens the stems and aids the development of new shoots in perennial crops and shrubs [2]. The calcium in bone meal can also help prevent common problems in vegetables such as blossom-end rot in crops like tomatoes, egg plants and peppers

[3]. Bone meal can be used as one part of a balanced organic fertilizer program for bulbs, roses and other plants that benefit from a slow-release form of phosphorus. It can feed plants for up to four months. Bone meal also has trace amounts of nitrogen and potassium, although it does not offer a high amount of either [4].

Shelf life of animal bones is increased and preserved through drying. Drying enables the food products to have reduced moisture content to an appreciable level such that when the food is stored; its shelf life can be increased [5]. To investigate the drying pattern of any food product, it is very important to also investigate the drying kinetics of the food product. Regardless of the drying pattern; thin-layer

*Corresponding Author: chuksmorgan@yahoo.com

Received: 10.06.2022

Accepted: 27.07.2022

Published on: 01.08.2022

Ekeke et al.,

drying equations are often used to describe drying behaviour in a systematic approach regardless of the controlling mechanism [2]. Many thin – layer drying models have been applied and ease of application of each varies. Due to the difference in moisture content of each food product, no one equation can describe all drying kinetics during transport phenomenon. Although the thin-layer drying of so many materials have been extensively studied and published in the body of literature, there is paucity of literature on the drying kinetics of cow bones, hence the reason for this study. The study focused on the drying kinetics of cow bone subjected to varying drying conditions in a laboratory scale oven.

2. MATERIALS AND METHODS

Fresh cow bones were collected and defatted using a stainless-steel knife after which a fine finish was attained with the use of sandpaper material. With the aid of a saw, the bones were cut on a bench vice (H. Duty, Model VSM 150) into slice thicknesses of 10mm, 15mm and 20mm.

To determine the initial moisture content of the bones on a dry basis, a sample of 10mm thickness was loaded into the laboratory oven and dried at a temperature of 120°C until constant mass was attained [6,7]. To obtain moisture content for the first sample, drying was carried out at intervals of 20 minutes for the first 60 minutes. Thereafter, drying time was increased to a period of 30 minutes interval for 2 hours, 40 minutes interval for a period of 1 hour 40 minutes and finally 50 minutes for 1 hour 30 minutes. After each drying period, the sample was retrieved from the oven, cooled in a desiccator for about 5mins and then weighed [8]. Moisture content on a dry basis was calculated after each drying time interval. The moisture content that corresponded to the time at which constant weight was achieved was taken as the equilibrium moisture content for that run. This approach was followed for drying temperatures of 140°C and 160°C for the 10mm bone sample slice thickness. The same procedure was repeated for the remaining slice thicknesses of 15mm and 20mm at 120°C, 140°C and 160°C respectively.

2.1 Drying Characteristics

The different drying data obtained were fitted to the tabulated drying models using MATLAB software version 7.9 as shown in Table 1. According to Erbay and Icier [9], modelling of

food material drying requires statistical methods of regression and correlation analysis. To determine the most applicable drying models for the cow bone samples in the oven, a graph of MR against t was plotted followed by a regression analysis with the thin layer drying mathematical models (selected from Table 1). The statistical indicators determine the selection of the most suitable models that can best describe the drying behavior of the food products. The indicators used in this work are the coefficient of determination (R^2) which provides information on the goodness of fit of the models; the sum of squares error (SSE) test and the root mean square error (RMSE) analysis, respectively. Higher values of R^2 of any of these models indicate how more appropriate the model will be when used to predict the drying characteristics of the cow bone samples, while lower values of $RMSE$ of any of the models will imply how more appropriate the model will be when used to predict the drying behavior of the drying sample [9-12].

Where t is time (min), k , g and $h(s^{-1})$ are drying constants; a , b and c are dimensionless model constants which indicate shape; $a^*(s^{-1})$ and $b^*(s^{-2})$ are constants determined from experimental data; l is a dimensionless empirical constant.

The moisture ratio (MR) is calculated using as [9]:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

where MR = moisture ratio, M_t = moisture content at time, t in kg water/ kg solids (w.b), M_e = equilibrium moisture content (kg water/ kg solids) and M_o = initial moisture content (kg water/ kg solids) all in wet basis (w.b). The expressions for R^2 , SSE and $RMSE$ are given as [9,10,20]:

$$R^2 = 1 - \frac{\sum_{i=1}^n (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^n (\overline{MR_{pre,i}} - MR_{exp,i})^2} \quad (2)$$

$$SSE = \sum_{i=1}^N (X_i - \bar{X})^2 \quad (3)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2 \right]^{\frac{1}{2}} \quad (4)$$

where, N stands for the number of observations, n is stands for the total number of constants in the drying model, $MR_{pre,i}$ represents the i th predicted moisture ratio data, $MR_{exp,i}$ is the i th experimental moisture ratio data, while $\overline{MR_{pre,i}}$ represents the mean of the predicted moisture ratio data.

Table 1: Thin layer drying models used to fit the drying kinetics of the cow bone

Model Name	Model Equation	References
Lewis	$MR = e^{(-kt)}$	[9]
Page	$MR = e^{(-kt^n)}$	[13]
Modified Page	$MR = e^{(-(kt)^n)}$	[14]
Wang and Singh	$MR = 1 + a^*t + b^*t^2$	[9]
Henderson and Pabis	$MR = ae^{(-kt)}$	[9]
Two term model	$MR = ae^{(-k_0t)} + be^{(-k_1t)}$	[15]
Logarithmic	$MR = ae^{(-kt)} + c$	[16]
Two term exponential	$MR = ae^{(-kt)} + (1 - a)e^{(kat)}$	[17]
Modified Henderson and Pabis	$MR = ae^{(-kt)} + be^{(-gt)} + ce^{(-ht)}$	[18]
Modified Page equation - II	$MR = e^{[-k(t/l^2)^n]}$	[9]

3. RESULTS AND DISCUSSION

The drying results of the time-variant moisture content of the cow bone samples at the experimental treatments of 120°C, 140°C and 160°C with varying slice thicknesses of 10mm, 15mm and 20mm, respectively were used to calculate the moisture ratios as shown in Tables 2 to 3. From Tables 2 to 3, it is obvious that the drying rate was relatively higher at the beginning of the drying experiments than what

was observed towards the end. This shows that as the drying time increases, there is usually a concomitant decrease in the drying rate, which causes a reduction in the moisture content of drying products. This reveals that the drying of the cow bone samples took place during the falling rate period, thus following a trend that is similar to the drying of food materials as reported by Onu et al. [21] and Ononogbo et al. [7].

Table 2: Drying at 120°C for different cow bone samples thickness

Drying time, t (min)	Moisture Ratio, MR Sample thickness		
	10mm	15mm	20mm
0	1.0000	1.0000	1.0000
20	0.4659	0.5481	0.4445
40	0.3704	0.5275	0.3857
60	0.3598	0.4692	0.3822
90	0.2739	0.3463	0.2697
120	0.2307	0.2603	0.1771
150	0.2199	0.1332	0.1700
180	0.1873	0.1244	0.1197
220	0.1436	0.1112	0.1089
260	0.1327	0.0891	0.0909
300	0.0776	0.0491	0.0583
340	0.0666	0.0402	0.0438
390	0.0445	0.0224	0.0292
440	0.0111	0.0090	0.0037
490	0.0000	0.0000	0.0000

The ten thin layer mathematical models used to fit the experimental data to test the model that gives the best drying characteristics of cow bone are shown in Table 1. The curve fitting of

the experimental data with the models was done for each of the models and the best model statistical parameters obtained were presented in Table 5. From Table 5, among the ten models

used, the Page and Two-term models produced the best results in terms of the values of the statistical indicators (R^2 , SSE and RMSE). However, the Page model gave higher Adjusted R^2 and lower RMSE values than the Two-term model, thus making it the best model to best describe the drying behavior of the cow bone samples. This clearly shows that in agreement with the work of Ojediran et al., [8], that drying behaviors of cow bone were better predicted by the Page model from the ten models investigated. The Page model parameters at the different temperatures and slice thicknesses

considered are shown in Table 6. The kinetic model parameters were estimated using the least squares method by using the measured experimental data. The minimization of the sum of squares of residuals (between calculated and measured values of the ten considered models) were performed by nonlinear regression, by means of the Trust Region optimization algorithm, implemented in the MATLAB built-in function. The kinetic parameters values estimated for 95% confidence is given in Table 5.

Table 3: Drying at 140°C for different cow bone samples thickness

Drying time, t (min)	Moisture Ratio, MR Sample thickness		
	10mm	15mm	20mm
0	1.0000	1.0000	1.0000
20	0.5770	0.6495	0.7525
40	0.4994	0.5039	0.5711
60	0.2501	0.3500	0.4145
90	0.2662	0.2499	0.3203
120	0.1908	0.2395	0.2677
150	0.1750	0.1544	0.2281
180	0.1342	0.1293	0.2151
220	0.1144	0.1250	0.1994
260	0.1023	0.1230	0.1938
300	0.0946	0.0866	0.1643
340	0.0701	0.0442	0.1204
390	0.0008	0.0083	0.1074
440	0.0008	0.0044	0.0875
490	0.0000	0.0000	0.0000

Table 4: Drying at 160°C for different cow bone samples thickness

Drying time, t (min)	Moisture Ratio, MR Sample thickness		
	10mm	15mm	20mm
0	1.0000	1.0000	1.0000
20	0.9364	0.6070	0.5464
40	0.8378	0.4255	0.3730
60	0.1466	0.3030	0.1855
90	0.1272	0.1617	0.1748
120	0.0964	0.1117	0.1696
150	0.0746	0.0661	0.1343
180	0.0710	0.0589	0.0850
220	0.0626	0.0537	0.0642
260	0.0491	0.0319	0.0472
300	0.0381	0.0233	0.0391
340	0.0222	0.0167	0.0231
390	0.0117	0.0059	0.0128
440	0.0048	0.0052	0.0039
490	0.0000	0.0000	0.0000

Table 5: Best criterion statistical parameters for the models

Model	SSE	R ²	Adjusted R ²	RMSE
Lewis	0.009166	0.992	0.9920	0.02559
Page	0.001837	0.9984	0.9983	0.01189
Henderson and Pabis	0.008139	0.9929	0.9923	0.02502
Modified Henderson and Pabis	0.002314	0.9974	0.9960	0.01603
Logarithmic	0.004455	0.9961	0.9955	0.01927
Wang and Singh	0.313	0.7199	0.6983	0.1552
Two-Term	0.001646	0.9986	0.9982	0.01223
Two-Term Exponential	0.002636	0.9977	0.9975	0.01424

Table 6: Page model parameters at the different temperatures and slice thickness

Sample Number	Processing parameters			Model parameters		Statistical parameters for Page's model			
	T (°C)	Size (mm)	Source	k (min ⁻¹)	N	SSE	R ²	Adj. R ²	RMSE
1	120	10	Cow	0.1709	0.4609	0.01263	0.9859	0.9846	0.03116
2	120	15	Cow	0.5695	0.6774	0.02288	0.9797	0.9779	0.14195
3	120	20	Cow	0.148	0.5057	0.01446	0.9847	0.9836	0.03335
4	140	10	Cow	0.08583	0.6085	0.0111	0.9893	0.9885	0.02992
5	140	15	Cow	0.0609	0.6725	0.008829	0.992	0.9914	0.02606
6	140	20	Cow	0.04087	0.7547	0.01314	0.9889	0.9881	0.0318
7	160	10	Cow	3.348E-8	4.316	0.05654	0.9629	0.9629	0.00635
8	160	15	Cow	0.04423	0.8094	0.001837	0.9984	0.9983	0.01189
9	160	20	Cow	0.1078	0.6087	0.01119	0.9890	0.9882	0.02934

Table 7: ANOVA table for the interaction of the three parameters on the cow bone samples

Source	Sum of square	Degree of freedom	Mean square	Fval	Pval
X1	0.01557	2	0.00779	0.98	0.4154
X2	0.00488	2	0.00244	0.31	0.7432
X3	1.91303	2	0.95652	120.7	0
X1*X2	0.03159	4	0.0079	1	0.4624
X1*X3	0.06535	4	0.01634	2.06	0.1783
X2*X3	0.00683	4	0.00171	0.22	0.9225
Error	0.0634	8	0.00792		

The appropriate model for the description of the thin layer drying kinetics of animal bone samples was chosen according to the criteria of Agarry et al., [1]. The criteria states that the model with the highest coefficient of regression (R² and adjusted R²), least sum of squares (SSE) and root mean square error (RMSE) will be used as the indicator of goodness of fit to the experimental data. With this criterion, the best model was found to be Page's Model with an R², adjusted R², SSE, and RMSE values of 0.9984, 0.9983, 0.001837 and 0.01189, respectively. The obtained Fischer test (F-test) values and the Probability value (P value) were calculated by the MATLAB software and presented in Table 7. The significance of each parameter or variable on the yield was examined for P values lower

than 5% since MATLAB uses a confidence bound of 95%.

From Table 8, we can conveniently conclude that time (X3), the interaction of temperature (X1) and time (X3) (i.e. X1*X3), and the time square term (X3²) had the greatest influence on the moisture ratio (MR). That is to say that, the time and the interaction between time and temperature play very significant roles in determining the MR of cow bone samples based on the experimental values gotten, which is in agreement with what was reported by Omolola et al. [22].

The ANOVA and regression analysis tables were based on 95% confidence bound to

estimate the significance or influence of each of the parameters on the overall MR of the cow bone samples examined. On that basis, Probability values (Pval) less than 5% are considered significant on the Moisture Ratio. However, the ANOVA results of Table 7 on the significance of the process parameters showed that it is not suitable for use as the appropriate basis to characterize the process. However, from the equation obtained, the model that characterizes the drying kinetics of the cow bones is given in Eqn (5):

$$= -1.6657 + 0.0281 * x(1) + 0.0229 * x(2) - 0.0023 * x(3) - 2.7217e - 4 * (x(1) * x(2)) -$$

$$1.2382e - 5 * (x(1) * x(3)) + 1.9625e - 5 * (x(2) * x(3)) - 7.1514e - 5 * x(1).^2 + 2.5111e - 4 * x(2).^2 + 5.0387e - 6 * x(3).^2 - (5)$$

Where y represents moisture ratio and x(1), x(2), x(3) represent drying temperature, drying time and bone slice thickness.

Minimizing the function of the variables using the optimization tool, the optimum moisture ratio was obtained at optimal process parameter values of 120°C, 356 minutes and 10mm for drying temperature, drying time and bone slice thickness respectively.

Table 8: Regression analysis table for the cow bone samples

Terms	Constant	X1	X2	X3	X1*X2	X1*X3	X2*X3	X1^2	X2^2	X3^2
Pval	0.3627	0.2651	0.6762	0.0268	0.2787	0.0473	0.4085	0.4172	0.8574	6.08e-6

Figs. 1 to 3 show the response surface plots of drying time, bone slice thickness and drying temperature on the moisture ratio of the cow bone samples. Fig. 1 shows the effect of bone slice thickness and drying temperature on the MR of the cow bone samples, and the optimum (lowest) moisture ratio was observed to be 0.05 at drying temperature and slice thickness values of 120°C and 10mm respectively. Fig. 2 shows the effect of drying time and bone slice thickness on the MR of the cow bone samples. From the figure, it can be observed that MR was

fairly constant at the initial drying time (0 min) across all slice thicknesses, but as time progressed there was a noticeable drop in MR over time until the moisture ratio approached zero. This agrees with what Onu et al., [21] reported that an increase in the drying temperature makes the food products to reach equilibrium faster. This shows clearly that temperature is an important parameter with strong influence on the product sample. Fig. 3 shows the influence of drying time and temperature on the MR of the bone samples.

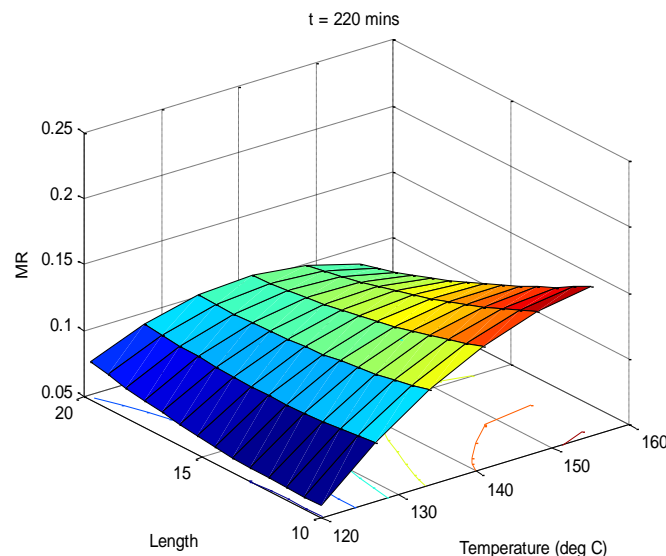


Fig. 1 Response surface plot showing interaction between slice thickness (length) (mm) and temperature (°C) as factors with moisture ratio as response

Ekeke et al.,

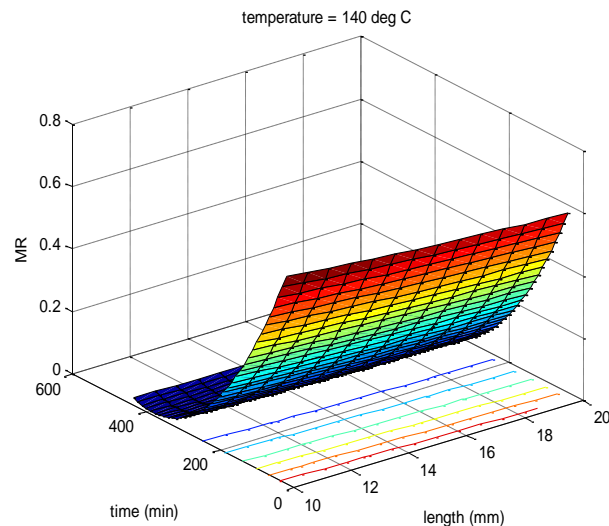


Fig. 2 Response surface plot showing interaction between time (min) and slice thickness (length) (mm) as factors with moisture ratio (MR) as response

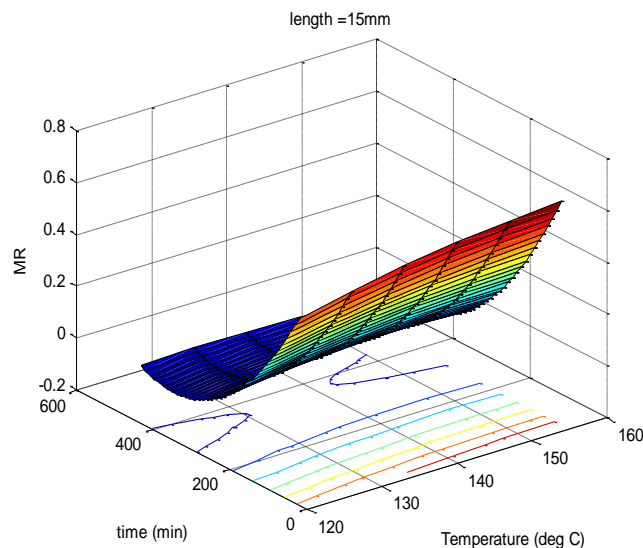


Fig. 3 Response surface plot showing interaction between time (min) and temperature (°C) as factors with moisture ratio (MR) as response variable

The 3-D response surface plots (Figs. 1 to 3) show the results of the significance of the interaction between the drying time, drying temperature and slice thickness. This relationship is also confirmed by the regression analysis and analysis of variance carried out, that time and temperature are the two most important factors in the drying of cow bone samples, which agree with works of Ojediran et al., [18], Omolola et al., [22] and Onu et al., [21] and that bone slice thickness only plays a secondary role.

4. CONCLUSION

The experimental study has shown that the drying rate of cow bone is to a great extent a

function of the drying time and temperature at which it is dried, as it was clearly observed that the effect of drying temperature and time have the most significant effects on the moisture ratios of the dried samples. The results of the study revealed that the drying of cow bone samples occurred in the falling rate period, which is in agreement with the drying trend of other solid materials reported in the literature. The curve fitting of the experimental data was carried out with ten known mathematical drying models to determine which that gives the best description of the thin-layer drying characteristics of the cow bone samples. The results obtained show the Page model as the best followed by the Two-term models due to

their best R^2 , SSE and RMSE values. Also, with the use of the optimization tool of the MatLab software, the optimum moisture ratio was obtained at optimal process parameter values of 120°C, 356 minutes and 10mm for drying temperature, drying time and bone slice thickness respectively.

REFERENCES

- [1] Agarry, S. E., Ajani, A. O., Aremu, M. O. 2013. Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination. *Nigerian Journal of Basic and Applied Science*, 21(1): 1-10.
- [2] Kadam, D.M., Goyal, R.K., Singh, K.K., Gupta, M.K. 2011. Thin layer convective drying of mint leaves. *Journal of Medicinal Plant Research*, 5(2): 164-170
- [3] Hi, C. L., Law, C. L., Cloke, M. 2008. Modelling Thin-Layer Drying Kinetics of Cocoa Beans during Artificial and Natural Drying. *Journal of Engineering Science and Technology*, 3(1): 1-10.
- [4] Chayjan, R. A., Salari, K., Shadidi, B. 2012. Modelling some drying characteristics of garlic sheets under semi-fluidized bed conditions. *Res. Agr. Eng.* 58(2): 73-82.
- [5] Doymaz, I. 2004. Pretreatment effect on sun drying of mulberry fruits (*morusalsa*, L.). *Journal of Food Engineering*, 65: 205-209.
- [6] Kouadio, C. J., Ghislaine, D. N. K., Assoi, Y.D., Kouamé, L. P. and Kamenan, A. 2017. Biochemical and Functional Properties of Yam Flour during the Post-harvest Conservation of *Dioscorea alata* Cultivar « Azaguié ». *Current Journal of Applied Science and Technology*, 21(6): 1-10.
- [7] Ononogbo, C., Nwufu, O.C., Nwakuba, N.R., Okoronkwo, C.A., Igbokwe, J.O., Nwadinobi, P.C., Anyanwu, E.E. 2021. Energy parameters of corn drying in a hot air dryer powered by exhaust gas waste heat: an optimization case study of the food-energy nexus. *Energy Nexus* 4: 1-8.
- [8] Ojediran, J. O., Raji, A. O. 2010. Thin-layer drying of millet and effect of temperature on drying characteristics. *International Food Research Journal*, 17: 1095-1106.
- [9] Erbay, Z., Icier, F. 2009. A Review of Thin Layer Drying of Foods: Theory, Modeling, and Experimental Results. *Critical Reviews in Food Science and Nutrition*, 50:441-464. Taylor and Francis Group, LLC.
- [10] Demir, V., Gunhan, T., Yagcioglu, A.K. & Degirmencioglu, A. 2004. Mathematical Modelling and the Determination of Some Quality Parameters of Air-Dried Bay Leaves. *Biosystems Engineering*, 88(3): 325-335.
- [11] Erenturk, S., Sahin, M., Gultekin S. 2004. The Thin-layer Drying Characteristics of Rosehip. *Biosystems Engineering*, 89(2): 159-166.
- [12] Kucuk, H., Midilli, A., Kilic, A., Dincer, I. 2014. A review on thin-layer drying-curve equations. *Drying Technol* 32(7):757-73.
- [13] Page, G. (1949). Factors in Influencing the Maximum Rates of Air-Drying Shelled Corn in Thin-Layer. MSc Thesis. Department of Mechanical Engineering, Purdue University, West Lafayette, IN, USA.
- [14] Overhults, D.G., White G.M., Hamilton H.E., Ross I.J. 1973. Drying soya beans with heated air. *Transactions of the ASAE*, 16(1), 112- 113.
- [15] Henderson, S. M. 1974. Progress in Developing the Thin – Layer Drying Equation. *Transaction of ASAC*, 17: 1167 – 1172.
- [16] Karathanos, V.T., Belessiotis, V.G. 1999. Application of a Thin Layer Equation to Drying Data of Fresh and Semi – Dried Fruits. *Journal of Agricultural Engineering*, 74:355-360.
- [17] Yagcioglu, A., Degirmencioglu, A., Cagatay, F. 1999. Drying Characteristics of Laurel Leaves under Different Conditions. *Proceedings of the 7th International Congress of Agricultural Mechanization and Energy*. (Eds: A. Bascetincelic), Cukurova University, Adana, Turkey, 26 – 27 May, pp. 565 – 569.
- [18] Kucuk, H., Midilli, A., Kilic, A., Dincer, I. 2014. A review on thin-layer drying-curve equations. *Drying Technol* 32(7):757-73.
- [19] Ojediran, J. O., Raji, A. O. (2010). Thin-layer drying of millet and effect of temperature on drying characteristics. *International Food Research Journal*, 17: 1095-1106.
- [20] Sanful, R., Addo, A., Oduro I., Ellis, W. 2015. Air Drying Characteristics of Aerial Yam (*Dioscorea bulbifera*). *Sch. J. Eng. Tech.*, 3(8):693-700.
- [21] Onu, C. E., Igbokwe P. K., Nwabanne J. T. 2017. Effective Moisture Diffusivity,

- Activation Energy and Specific Energy Consumption in the Thin-Layer Drying of Potato. *International Journal of Novel Research in Engineering and Science*, 3(2): 10-22.
- [22] Omolola, A. O., Jideani, A. I. O., Kapila, P. F. 2014. Microwave Drying Kinetics of Banana (Luvhele Spp). *Journal on Processing and Energy in Agriculture*, 18(2): 68-72.